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RESEARCH MEMORANDUM

SIMPLIFIED PROCEDURES FOR ESTIMATING FLAP-CONTROL LOADS AT SUPERSONIC SPEEDS

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FOR AERONAUTICS

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SIMPLIFIED PROCEDURES FOR ESTIMATING FLAP-CONTROL LOADS AT SUPERSONIC SPEEDS

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SUMMARY

An investigation has been made to determine the possibility of using simplified procedures for the estimation of control loads at supersonic speeds. The results of the investigation indicate that relatively simple procedures are possible for the estimation of loadings on flap-type controls at supersonic speeds for the case where no flow separation occurs ahead of the hinge line. For tip-type controls, the simplified procedures have been tested only in a few cases and need further development. For controls with swept hinge lines, experimental data are lacking, but it is anticipated that the procedures developed for the unswept hinge-line controls will apply provided that there is no flow separation at the hinge line or that the sweep angle is not too large. In general, the loadings predicted by the simplified procedures are in better agreement with experiment than is unmodified three-dimensional linear theory.

INTRODUCTION

The estimation of control loads at supersonic speeds from linear theory or other available techniques has proved to be rather complicated and tedious. In particular, there is a need for rapid methods of predicting control loads with reasonable accuracy for preliminary design. The objective of this paper is to present such a technique. Of course, it should be stressed that simplicity is often achieved only at a sacrifice in ultimate accuracy. Another restriction that has been imposed in this paper is that the boundary layer on the wing is turbulent.

SYMBOLS

b	wing span
c	local chord
p	static pressure

[redacted]

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P pressure coefficient, $\frac{p_l - p}{q}$

q dynamic pressure

M free-stream Mach number

y spanwise distance

α angle of attack, deg

δ control deflection, deg

Δc_{n_f} increment in section normal force on control

Δc_{n_w} increment in section normal force on wing plus control

Δc_{m_f} increment in section pitching moment due to load on control

Δc_{m_w} increment in section pitching moment due to load on wing plus control

K constant

Subscripts:

l local

1 ahead of control hinge line

2 behind control hinge line

av average

cr critical

TRAILING-EDGE CONTROLS

Basic Flow Types

In figures 1 and 2 are depicted two basic types of flow over a flap-type control. Figure 1 shows a flow that adheres closely to the airfoil surface. This type of flow occurs only at relatively low angles of attack and control deflection. Some theoretical and experimental chordwise pressure distributions characterized by this type of flow are indicated in the lower part of figure 1. These results were obtained at a Mach number of 1.61 on an essentially two-dimensional station on a trapezoidal wing having a hexagonal section. The symbol P denotes the usual pressure coefficient and x/c, the chordwise station in terms of the local chord. The agreement between linear theory and experiment is seen to be good except that experimentally the flow does not expand as much around the corner just ahead of the control hinge line as is indicated by theory and the load over the control is only about 70 percent of the theoretical load.

The sketch in the upper part of figure 2 illustrates conditions where the flow is separated up to the hinge line on the control low-pressure surface and on the main wing ahead of the hinge line on the side of the control high-pressure surface. Separated flows such as these occur when the angles of attack and control deflection are large enough to produce very strong shocks at the control trailing edge or hinge line. These strong shocks cause the boundary layer on the wing or control to separate. The plot in the lower part of figure 2 shows the corresponding pressure distributions. Obviously, the agreement between theory and experiment is not good; on the control upper surface, theory even indicates a pressure lower than absolute vacuum.

In this paper it is impossible to discuss thoroughly all the types of flow illustrated in figures 1 and 2. Experience has shown, however, that separation from the control low-pressure surface occurs first, is generally restricted to the control itself, and has a relatively small effect on the control aerodynamic characteristics. The chordwise pressure distribution in such a separated-flow region is usually uniform as indicated for the control upper surface in figure 2. Thus, for conditions where flow separation does not occur ahead of the hinge line, the control chordwise loadings closely resemble the uniform loading shown for an unseparated-flow condition in figure 1 even though the loading may be asymmetrical between the upper and lower surfaces. In this paper the discussion of flap-type controls will be limited to conditions where flow separation may be present on the control itself but does not occur ahead of the control on the main wing.

Method of Approach

As was mentioned previously, within the limitations just described the control chordwise loadings resemble the one shown in figure 1. The crux of the situation lies in this uniform loading; for if this loading is always a constant percentage of the theoretical value, the loading per unit degree of angle of attack or control deflection can be readily estimated from simple two-dimensional considerations by taking the proper proportion of the linear theory loading given by $4/\sqrt{M^2 - 1}$. This ratio of experimental to theoretical loading is defined as K and, as indicated by the results in figure 1, is equal to about 0.7. Thus, if it can be shown that effects of α and δ can be considered independently of one another, that the span loading is uniform, and that the constant K always remains about 0.7, then a simple procedure for estimating control span loadings becomes available. Before proceeding with these discussions, however, it is desirable first to indicate the manner in which the limiting-flow conditions can be determined and the effect of Mach number.

Flow-Separation Parameters

In figure 3 are presented two criteria to aid in determining the limiting conditions of flow separation ahead of the control hinge line. At present, it is not known which is the better criterion. In figure 3 on the left, $(p_2/p_1)_{cr}$ relates the static pressures ahead of and behind the hinge line for the initial appearance of separation. In figure 3 on the right $\left(\frac{p_2 - p_1}{q_1}\right)_{cr}$ describes the pressure rise in terms of the local dynamic pressure ahead of the shock required for flow separation. The local flow Mach number ahead of the control surface is M_1. The experimental data are from control tests on a trapezoidal wing at $M = 1.61$ and 2.01. The data are compared with the results compiled by Bogdonoff and Kepler (ref. 1) and by Lange (ref. 2). Agreement is only fair in both cases. It is suggested that an average value indicated by the present experimental results be used to determine the limiting control angle. In general, for the usual type of control configuration with sharp trailing edge, the limiting δ will tend to approach 20°. For controls with thickened trailing edges and for controls operating at free-stream Mach numbers at or below 1.6 at fairly high angles of attack, where the local Mach number becomes low and shock detachment becomes imminent for small pressure-rise ratios as indicated by the plots in figure 3, the limiting angles decrease.

Effect of Mach Number

Figure 4 shows the effect of Mach number on the chordwise pressure distributions. The sketch at the top of figure 4 indicates that the data were obtained on an essentially two-dimensional station on a trapezoidal wing at Mach numbers of 1.61 and 2.01. The ordinate is the normalized pressure coefficient and x/c, the station in terms of the local wing chord. Two angle-of-attack and control-deflection conditions, as indicated, are shown. The results for the two test Mach numbers are seen to be in very good agreement despite the fact that flow separation has already occurred ahead of the control at $M = 1.61$ on the side of the control high-pressure surface (indicated by the square and diamond symbols) and the control angle therefore is somewhat beyond the limit previously described. On the basis of other results it appears that this type of correlation should be possible to considerably higher Mach numbers than indicated here, perhaps to $M = 3.5$ or 4.0.

Spanwise Loadings

The use of the previously suggested uniform-loading procedure in determining the span-load distributions for a full-span flap-type control is illustrated in figure 5 for a Mach number of 1.61. The control is denoted by the shaded area in the sketch in the upper part of the figure. The wing shown, incidentally, has 23° sweep at the leading edge, and thus the control is influenced by conical flow across nearly the entire span. In the plot on the left of figure 5 are presented the section normal-force parameters for the load on the control due to α against the semi-span distance parameter $\frac{y}{b/2}$. On the right-hand side of figure 5 are shown the section normal-force parameters for the load on the control due to δ. The dashed lines indicate span loadings computed from linear theory. The experimental points in the plot on the left-hand side of the figure cover a range of α from 0° to 15°, whereas the experimental points in the plot on the right-hand side cover a δ range from -20° to 20°. The solid lines represent the span loadings obtained by assuming a uniform loading both chordwise and spanwise with a point value of $0.7 \times 4/\sqrt{M^2 - 1}$ for both the angle-of-attack and control-deflection cases. A comparison of the results indicates that the experimental spanwise loadings are in good agreement with the span loadings computed simply on the basis of uniform loading and the aforementioned point-loading parameter. The agreement is considerably better than that between experiment and the unmodified linear theory. It should also be noted that the effects of the wing tip and control tip were relatively small and can be neglected to a first order. For the case of uniform loading the center of pressure for the complete control is predicted to be at the control center of area; the experimental spanwise center-of-pressure results are in good agreement with this prediction.

Figure 6 shows the application of the simplified technique for estimating span loadings to a partial-span control. The control is indicated by the sketch at the top of figure 6. Ordinates and abscissas are as in figure 5 except that the incremental wing-span loading parameter is used to show the effects of control deflection on wing carryover. The flap section normal force is equal to the wing section normal force within the span covered by the control when there is no flow separation ahead of the hinge line, as is the case here. Linear theory, uniform loading calculations, and experimental results are indicated by dashed lines, solid lines, and experimental points, respectively. The agreement between the uniform-loading span-load distribution and experiment is seen to be again considerably better than that between unmodified linear theory and experiment. The experimental spanwise center of pressure for the control is also very close to the center of control area as predicted by uniform-loading calculations.

Figure 7 has been prepared to illustrate how closely the spanwise distribution of chordwise pitching moment due to the loads on the control can be predicted. These results are for the same control configuration shown in figure 6. The same line and symbol code applied except that the ordinates in this figure are the increments in section wing pitching moments contributed by the flap from the loading due to α or δ. The moments are taken about the center of the mean aerodynamic chord or about the 0.564 root-chord station, as indicated in the sketch. Again, the simple uniform load predictions are in good agreement with experiment; thus, the experimental chordwise loadings are uniform and the experimental control longitudinal center of pressure is near the center of control area.

For controls operating in a strongly conical flow field, such as on a highly swept delta wing, the problem of estimating the spanwise control loading due to α becomes more complex and the procedure must be modified. This condition is shown in figure 8 for a full-span flap-type control on a 60° delta wing at a Mach number of 1.61. For the loading due to control deflection, the uniform-loading procedure presented in previous figures still applies. The loading on the control due to α, however, increases across the span to a peak at about the 87-percent semispan station. Inasmuch as the form of this loading is dependent upon the relationship between the Mach line from the wing apex and the wing leading edge and must be preserved, the following technique was evolved. The chordwise loading at any spanwise station is assumed to be constant and equal to the three-dimensional linear-theory value at the flap midchord point multiplied by $K = 0.7$. The spanwise variation in loading is thus introduced by the spanwise variation in the midchord point loading.

The agreement between these constant-chord-load calculations and experiment is good. Although the data are not shown, the agreement between the calculated spanwise variation of pitching moment and experimental results is equally good.

The exact region where the uniform-loading procedure should give way to this modified procedure is difficult to define because of the gradual transition from one type of loading to the other. In general, however, the modified procedure should be used when the Mach line from the wing apex begins to approach the wing leading edge and the edge tends to become sonic or subsonic.

TIP CONTROLS

Basic Problems

The problem of estimating loadings on tip controls is considerably more complex than that of the flap-type control and the simplified methods of estimating the loadings have not been as fully developed. Although tip-control configurations generally are not afflicted with hinge-line separation, they are affected by additional variables such as leading-edge separation and shock detachment and are considerably more sensitive to control section and wing-control parting-line effects. Consequently, the chordwise loadings can change rapidly with changes in any one of these variables and the loading often has no resemblance to that predicted by linear theory. It appears, however, that, despite all these complications, it may eventually be possible to develop a relatively simple procedure for estimating the loadings on at least certain types of tip controls.

Typical Spanwise Loading

Figure 9 shows the results of some such simple calculations for a half-delta tip control. The control is depicted by the shaded area in the sketch of the wing. The ordinate is the section pitching moment due to α or δ taken about the middle of the mean aerodynamic chord or the 2/3 station of the root chord. Linear theory is indicated by the dashed lines and the uniform loading predictions by the solid line. The first thing to notice is that a K-factor of 0.70 no longer always guarantees good agreement between the uniform-loading calculations and experiment, as exemplified by the control-deflection case. In order to overcome this deficiency, the constant K was modified to give a good fit between calculated and experimental section normal-force parameters, which are not shown here. The resultant values of K were 0.85 for the loading due to α and only 0.44 for the loading due to δ. This large decrease for the control-deflection case is to be expected because of the strongly three-dimensional flow over a very low-aspect-ratio shape. The calculated section pitching-moment parameters for these modified values of K are in fair agreement with experiment for the loading due to δ but tend to be somewhat high for the loading due to α. Better agreement as regards both magnitude and shapes of the curves can be obtained in the latter case by assuming a trapezoidal rather than uniform chordwise loading.

The assumption of uniform spanwise pressure appears to be reasonably adequate, as does the assumption of no wing carryover of the control load due to δ.

At present, these simplified procedures for estimating loads on tip controls have been applied to only a limited number of cases. Indications are that the value of K may be dependent upon control configuration and Mach number. Obviously, further analysis of available data must be made before final recommendations can be given.

CONTROLS WITH SWEPT HINGE LINES

At present, there is a lack of experimental data on which to develop simple procedures for estimating loadings on controls with swept hinge lines. On the basis of available knowledge, however, it may be anticipated that the procedures described previously should apply provided there is no hinge-line separation, the sweep angle is not too high, and the normal component of the velocity at the hinge line is used.

CONCLUDING REMARKS

In conclusion, it may be stated that simplified procedures have been developed for the estimation of control loadings on flap-type controls at supersonic speeds for the case where no flow separation occurs ahead of the hinge line. For tip-type controls, the simplified procedures have been tested only in a few cases and need further development. For controls with swept hinge lines, experimental data are lacking, but it is anticipated that the procedures developed for the unswept hinge-line controls will apply provided that there is no flow separation at the hinge line or the sweep angle is not too large. It might also be mentioned that, in general, the loadings predicted by the simplified procedures are in better agreement with experiment than the unmodified three-dimensional linear theory is.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 21, 1955.

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2. Lange, Roy H.: Present Status of Information Relative to the Prediction of Shock-Induced Boundary-Layer Separation. NACA TN 3065, 1954.

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TYPICAL FLOW TYPES
NO SEPARATION

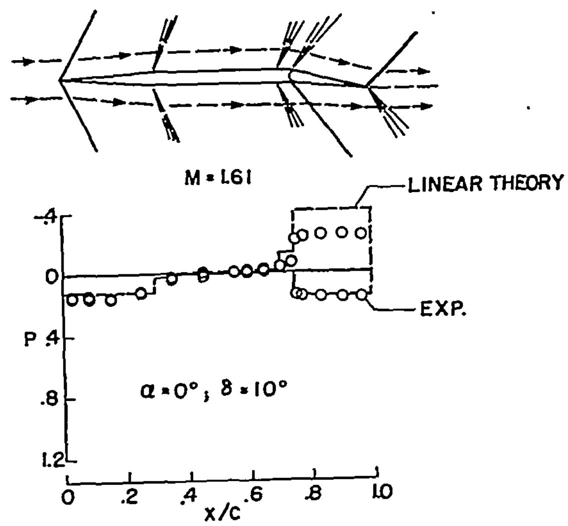

Figure 1

TYPICAL FLOW TYPES
WITH SEPARATION

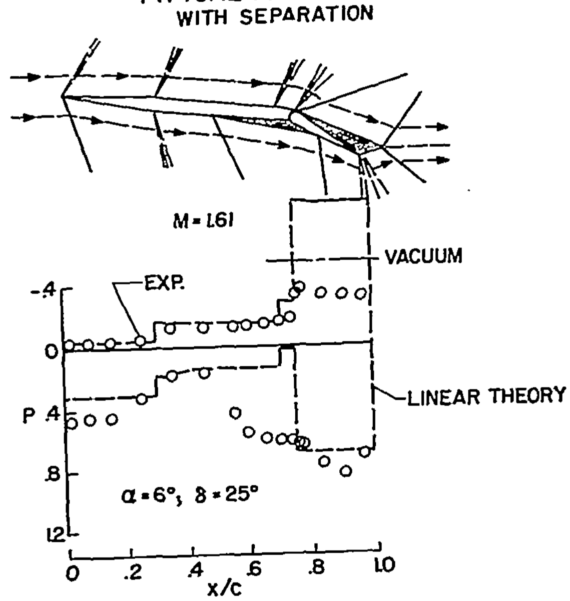

Figure 2

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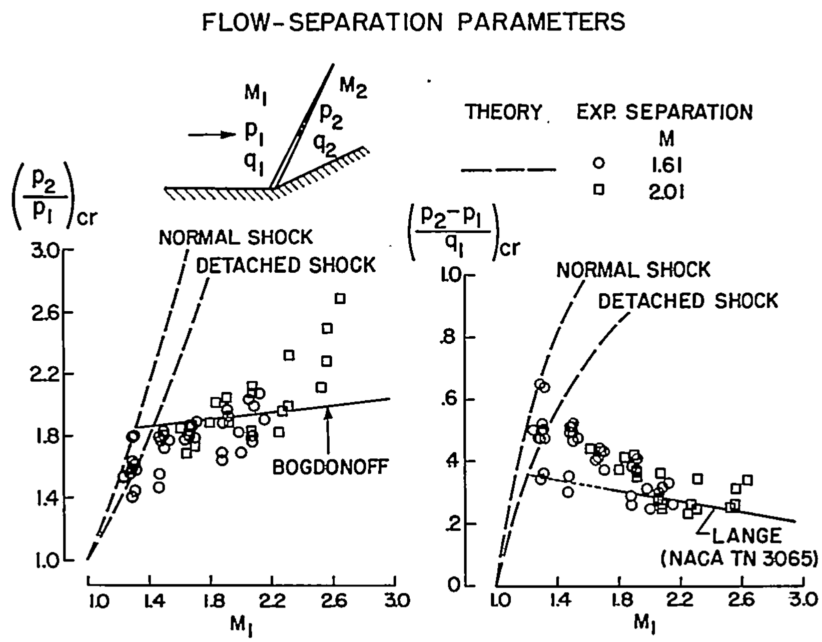

Figure 3

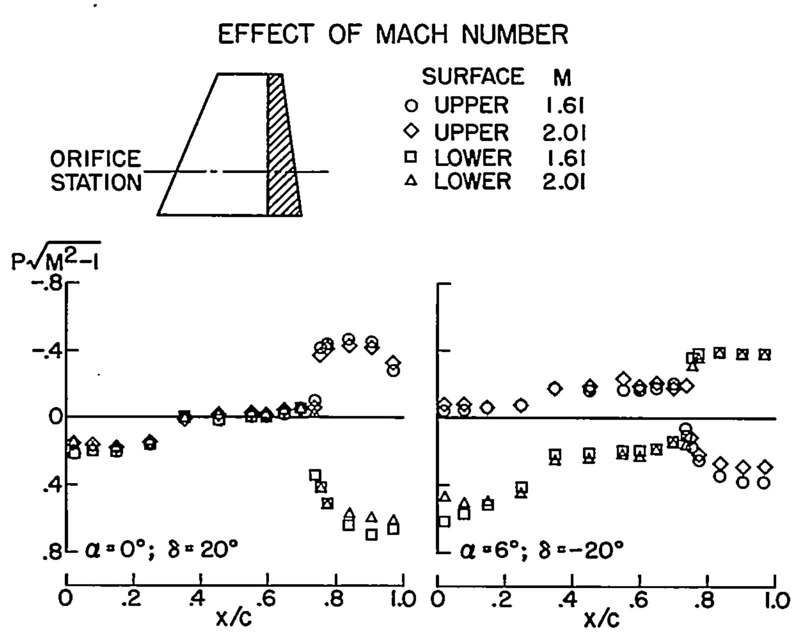

Figure 4

SPAN LOADING ON FULL-SPAN CONTROL

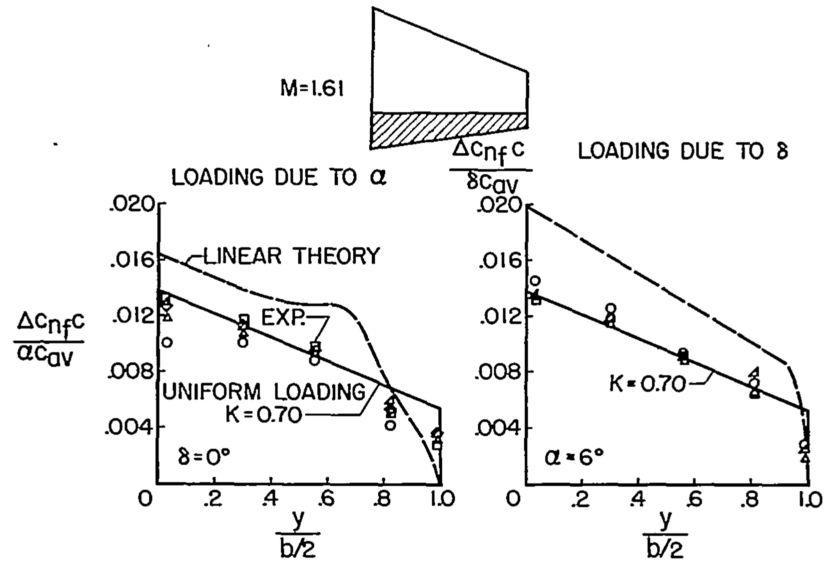

Figure 5

SPAN LOADING ON PARTIAL-SPAN CONTROL

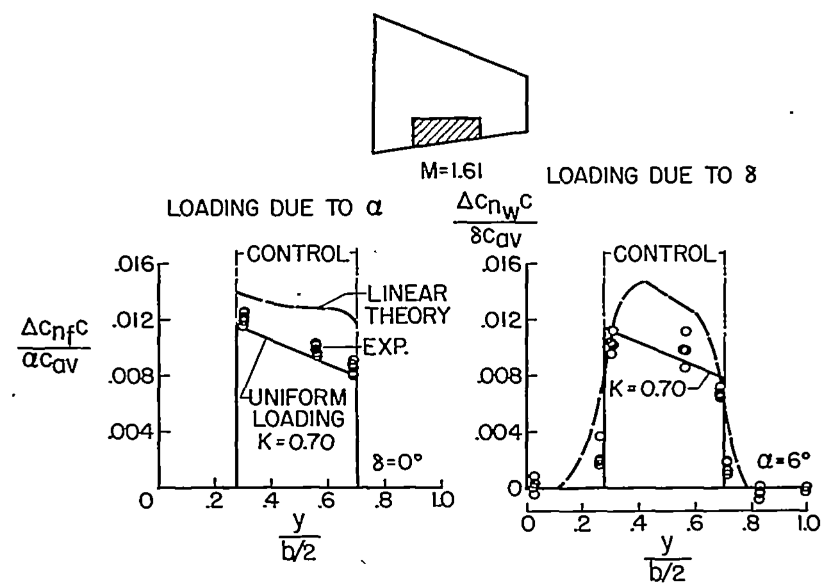

Figure 6

PITCHING-MOMENT DISTRIBUTION ON PARTIAL-SPAN CONTROL

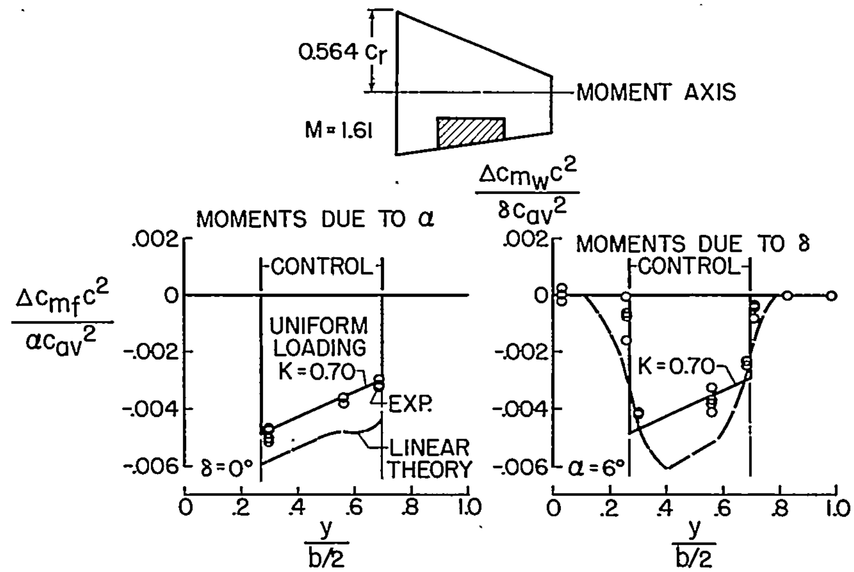

Figure 7

EFFECT OF LARGE SWEEP ON SPAN LOADING

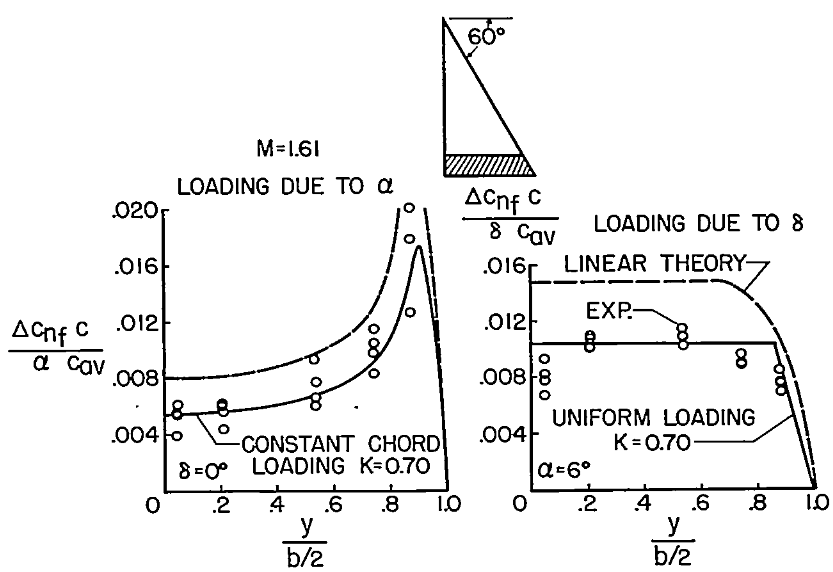

Figure 8

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PITCHING-MOMENT DISTRIBUTION FOR TIP CONTROL

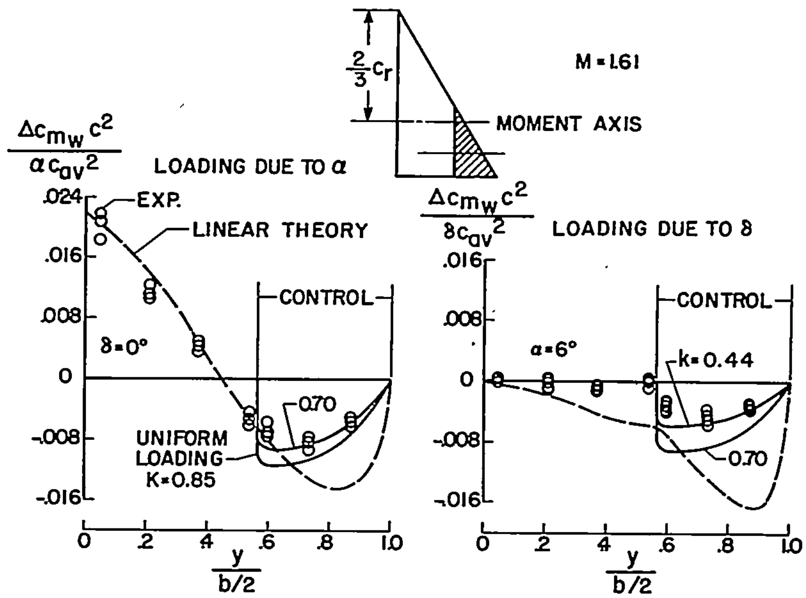

Figure 9

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